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BUREAU OF STANDARDS

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AN IMPROVED FORM OF STANDARD IONIZATION CHAMBER¹

By Lauriston S. Taylor and George Singer

ABSTRACT

A modification of the open-air parallel plate ionization chamber, readily portable and adapted to field use, is described. In this chamber, narrow guard plates are supplemented by a system of 10 guard wires across the ends of the chamber. The wires are so spaced that X-ray scattering from them is negligible. By this means a uniform electrostatic field between electrodes is obtained without the use of wide guard plates and the large plate-to-shield spacing necessary in the primary standard. This design has permitted a decrease in the volume and weight of the secondary standard by a factor of 15.

The results of direct comparisons between this chamber and the primary standard are given and indicate that the Roentgen can be reproduced by the former with the same accuracy as the primary standard. The problem of diaphragming is identical for the two chambers, and for a given tube the same inverse power law holds for both. Like the standard chamber, the new chamber does not require that corrections be made for differences in X-ray quality.

Any of the usual electrostatic measuring systems may be used with this chamber although for precise work a null or current compensation system is desirable.

It is expected that this type of chamber will be found useful in the international comparisons of the Roentgen now pending, for which purpose the "fingerhut-kammer" is generally inadequate.

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I. INTRODUCTION

The unit of intensity of an X-ray beam has been defined² in terms of the ionization produced in 1 cubic centimeter of unrestricted atmospheric air³; and as a result the air ionization chamber is, at least temporarily, established as the primary standard for X-ray intensity measurements.

Two distinct types of standard ionization chambers have been used; (a) The pressure air chamber, designed by Thaller⁴ and by Behnken^{5, 6} to give comparatively large ionization currents, meas-

¹ Paper read before Radiological Society of North America, Toronto meeting, December 2 to 6, 1929.

² Second International Congress of Radiology, Stockholm; July 23 to 27, 1928.

³ Paragraphs 2 and 3. "Report of International X-Ray Unit Committee" (Recommended) "2. That this International Unit be the quantity of X-radiation which when the secondary electrons are fully utilized and the wall effect of the chamber is avoided, produces in 1 cubic centimeter of atmospheric air at 0° C. and 76 cm. mercury pressure such a degree of conductivity that one electrostatic unit of charge is measured at saturation current." (Recommended.) "3. That the International Unit of X-radiation be called the 'Roentgen' and that it be designated by the small letter r."

⁴ R. Thaller, O. Berg. and W. Schwerdfeger, Wissenschaftliche Veröffentlichungen aus dem Siemenskonzern, 3, p. 162; 1924.

⁵ H. Behnken, Zeit. für Techn. Phys., 5, p. 3; 1924.

⁶ H. Behnken, Zeit. für Techn. Phys., 2, p. 563, 1926.

unable without the use of extremely sensitive instruments; (b) The atmospheric pressure air chamber, of which the construction and manipulation is comparatively simple. The first type was employed by the Physikalisch-Technischen-Reichsanstalt until their very recent adoption of a cylindrical form of atmospheric air chamber. In this country the second type has been used exclusively.

The atmospheric or open-air chamber was conceived as a result of Villard's definition of the "*e*" unit in 1908,⁷ and was later developed by Friedrich.⁸ As a result of further refinements by Duane,⁹ Glasser,¹⁰ Failla,¹¹ Kustner,^{12, 13} the authors,^{14, 15} and others, it is now apparently adequate for present demands. Using well-controlled, constant voltage on the X-ray tube, correct diaphragming of the X-ray beam and a refined measuring technique, the Roentgen can be reproduced at the present time at the National Bureau of Standards with a mean deviation of about ± 0.5 per cent.¹⁶

It is not sufficient, however, that the unit be duplicable in any one laboratory, but there must be also good agreement between the units as determined by all standardization laboratories. In the establishment of standards, it is obviously desirable to have them correct to one significant figure better than the magnitudes they are used to certify. Applied in the case of the international Roentgen unit, if medical practice demands an accuracy of 5 per cent in the calibration of its ionometers, the national standardization centers should bring about an agreement, if possible, between their respective standards of 0.5 per cent. There has been as yet, however, no direct check of the Roentgen between the national standardizing laboratories.

The only comparison of international character was made by Behnken¹⁷ in 1927 before a standard was developed at the Bureau of Standards. He found at the time an agreement of about ± 4 per cent between several American and German laboratories and the Reichsanstalt. The only basis at present for agreement between the bureau and the Reichsanstalt rests on a comparison recently made between the former and the Cleveland clinic which had been found to be within about 4 per cent of the Reichsanstalt.

Behnken's medium for transferring the unit was a carefully constructed ionometer with a magnesium thimble chamber and a uranium oxide auxiliary radiation standard for controlling its sensitivity. At that time this was the best known means for effecting such a comparison, but later work—particularly that of Braun and Kustner^{18, 19} and this laboratory^{20, 21}—has proved it to be inadequate for the high precision necessary. In a recent paper it was shown that while a thimble chamber ionometer is sufficiently accurate for intensity measurements in X-ray therapy it is liable to errors due to such factors as

⁷ A. Villard, *Arch. d'Elec. Med.*, p. 692; 1908.

⁸ Kroenig and Friedrich, *Radiation Therapy*; 1922.

⁹ W. Duane and E. Lorenz, *Am. J. Roent.*, **19**, p. 461; 1928.

¹⁰ O. Glasser and V. V. Portmann, *Am. J. Roent.*, **19**, p. 47; 1928.

¹¹ G. Failla, *Am. J. Roent.*, **21**, p. 47; 1929.

¹² H. Kustner, *Phys. Zeit.*, **28**, p. 797; 1927.

¹³ H. Kustner, *Strahlen.*, **27**, p. 331; 1928.

¹⁴ L. S. Taylor, *B. S. Jour. Research*, **2**, p. 771; 1929.

¹⁵ L. S. Taylor, *B. S. Jour. Research*, **3**, p. 807; 1929.

¹⁶ L. S. Taylor, *Radiology*, **14**, p. 3; 1930.

¹⁷ H. Behnken, *Strahlen.*, **29**, p. 192; 1928.

¹⁸ R. Braun and H. Kustner, *Strahlen.*, **32**, p. 550; 1929.

¹⁹ R. Braun and H. Kustner, *Strahlen.*, **32**, p. 739; 1929.

²⁰ L. S. Taylor and G. Singer, *B. S. Jour. Research*, **4** (RP 169), p. 631; 1930.

²¹ L. S. Taylor, *Radiology*, **15**, p. 227; 1930.

the "wall effect,"²² nonuniform distribution of ionization within the chamber and the effective chamber length, all of which render such an instrument incapable of the precision attainable with the standard. If the various standards can not themselves be directly compared, the comparison instrument should have a precision at least as good as the standards.

With this problem of agreement in mind, at the time the present primary standard was being developed, efforts were also directed toward the design of a readily portable secondary standard, the accuracy of which would be equivalent to that of the primary.

II. CONSTRUCTION

In the design of a standard chamber, the fulfillment of certain necessary requirements renders the instrument large and heavy. For example, the plate spacing must be sufficient so that a negligible number of photo-electrons strike them, thus decreasing the amount of measured ionization produced by a given beam. Duan,²³ Failla,²⁴ and Glasser²⁵ found for a parallel plate ionization chamber with the beam passing centrally between the plate that a spacing of 10 cm was sufficient. In order to permit the use of a wider beam of X rays, the standard chamber here used has a plate spacing of 12 cm.

The width of the guard plates must be about one and one-half to two times the plate spacing for this type of chamber^{26, 27} in order that there be a perfectly parallel electric field across the whole width of the collector electrode. Thus, for a plate spacing of 12 cm, the guards must be about 20 cm wide.

Also, if the plate system is to be inclosed in a grounded metal box for electrostatic and X-ray shielding, the spacing between the charged plate and box must be at least that of the interplate spacing.

On account of these considerations the present standard chamber is necessarily very large and unwieldy. The cylindrical chamber used by Behnken is a little less so, but not enough to permit transportation and field use.

It has not been found possible heretofore to decrease either the interelectrode spacing or the spacing between the electrodes and the grounded case. However, by means of a guard wire system, it has been found possible for a plate spacing of 12 cm to reduce the guard plate width from 18 to 5 cm and, likewise, the distance between high potential electrode and grounded case from 12 to 3 cm.

This modified type of ionization chamber is shown diagrammatically in Figure 1 from which it is seen that the guard plates are relatively narrow and the wall spacing small; whereas, ordinarily, such narrow guard plates would be entirely inadequate to insure a parallel field at the center of the chamber.

The field is rendered parallel by placing 10 small aluminum guard wires (*a*, *b*, *c*, — — —) across the ends of the chamber parallel to the electrodes and about 1.1 cm apart, except for the center pair which are spaced about 1.6 cm apart. To each of these wires, beginning at

²² L. S. Taylor and G. Singer, see footnote 20.

²³ W. Duane and E. Lorenz, *Am. J. Roent.*, 19, p. 461; 1928.

²⁴ G. Failla, *Am. J. Roent.*, 21, p. 47; 1929.

²⁵ O. Glasser and V. V. Portmann, *Am. J. Roent.*, 21, p. 47; 1929.

²⁶ G. Failla, *Am. J. Roent.*, 21, p. 47; 1929.

²⁷ L. S. Taylor, *B. S. Jour. Research*, 2, p. 771; 1929.

the one nearest the guard, is applied a potential greater than that of the preceding wire by one-tenth the total voltage used to saturate the chamber. Thus, for 2,000 volts applied to the chamber, the wires (*a*, *b*, *c*, . . .) have potentials of 200, 400, 600, . . . volts. This is easily accomplished by a series of 11 one-half megohm resistors connected in series between ground and the high potential plate, the successive guard wires connecting successive resistors.²⁸ The electric field is thereby corrected as sketched in Figure 1.

Common grid-leak resistors may be used for the potential divider, provided they remain essentially constant with respect to each other. Wire-wound half-megohm resistors are more reliable but require more space. The potential of each wire was carefully checked with an electrostatic voltmeter and found to have the proper value.

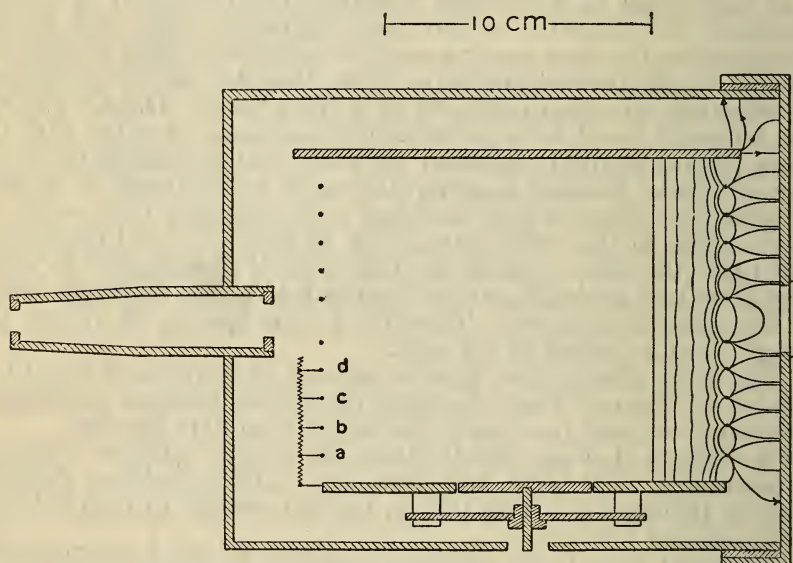


FIGURE 1.—Diagrammatic cross section of ionization chamber showing some of the lines of force as affected by the guard wire system

A photograph of the assembled electrode system is shown in Figure 2. In this the resistors are mounted on a hard-rubber sheet and the wires spaced on hard-rubber rods, the surface leakage of this material being negligible compared with that of the resistors. One of the four hard-rubber spacer rods may be replaced by a high resistance graphite rod and this used as the potential divider. Such a device, however, renders the chamber less rugged.

The electrode system is completely surrounded by a lead box braced with brass where necessary. Although this surrounding case is only 3 cm from the edges of the electrodes, this does not in any way affect the field within the chamber, since the potential wires provide sufficient field correction. Figure 3 shows this ionization chamber completely assembled with a flexible cable to connect to the electrostatic measuring system.

²⁸ This type of application of electrostatic shielding of the space between parallel plates at different potentials was first used by H. B. Brooks who developed the idea in 1916 and applied it to the design of an attracted disk electrometer, C. Snow, B. S. Jour. Research, 1 (RP17), p. 513; 1923.

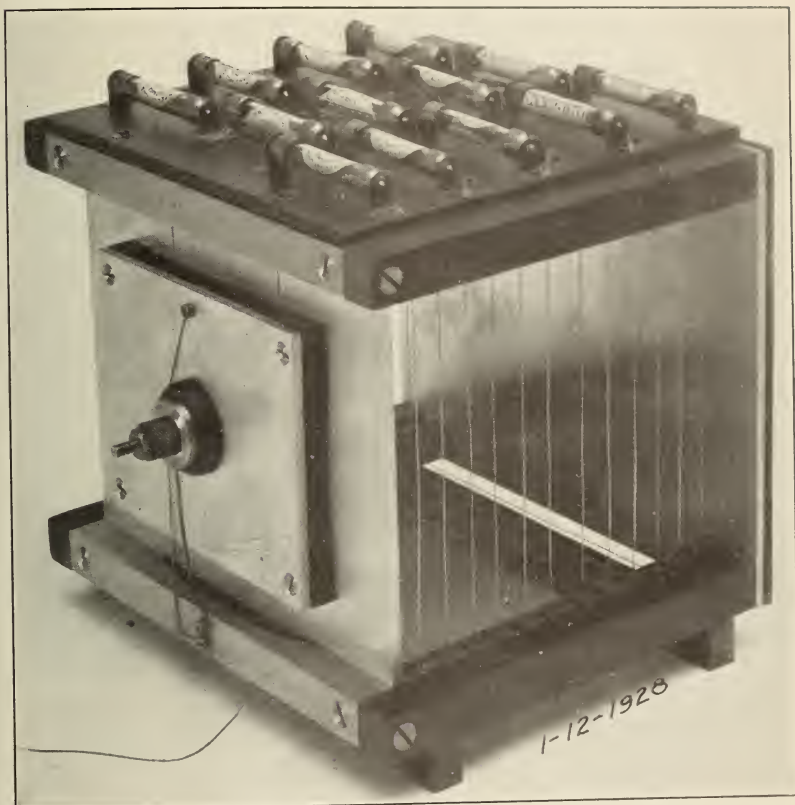


FIGURE 2.—Assembled electrode system showing guard wires and potential divider

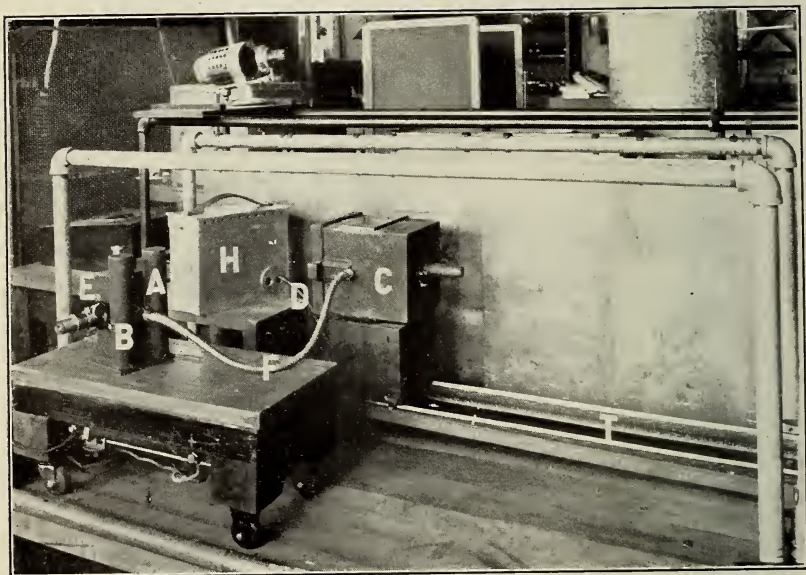


FIGURE 3.—Complete ionization chamber system, including electrometer *E*, and high potential generator *H*, mounted on track *T*, facing X-ray tube

The diaphragm system used with this is designed in accordance with that of the primary standard³⁰ and is held in place by a lead-lined brass tube which fastens to the front of the ionization chamber. The diameter of the limiting diaphragm is 0.8 cm so that the direct beam passing through the chamber does not strike any of the guard wires. At the inner end of the lead tube is a diaphragm 1.2 cm in diameter which minimizes the effect of any radiation scattered from the front diaphragm and the lead walls. At the back of the chamber the beam passes out through a 3-cm hole covered with a thin sheet of celluloid to eliminate air drafts.

The electrostatic measuring system is essentially the same as that used with the standard chamber and has been previously described in detail.³¹ For field use, where the highest precision is not demanded, an idiostatic string electrometer system is used. The nature and magnitude of the error introduced through the use of this method has been previously investigated,³¹ so that for the present needs the necessary correction can be made fairly closely. A portable idiostatic string electrometer, *E* (fig. 3) is connected directly to the

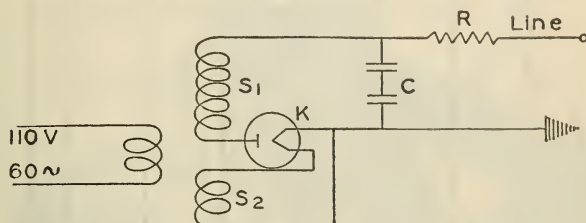


FIGURE 4.—Diagram of portable kenotron rectified 2,200-volt generator

ionization chamber, *C*, by means of a flexible cable, *F*. *A* and *B* are concentric cylinder condensers used for changing the sensitivity of the measuring systems.³²

The potential used to saturate the chamber is supplied from a compact portable kenotron rectifier shown in figures 3 (*H*), 4, and 5. A low power 110-volt, 60-cycle transformer (*R*), specially built, is provided with two secondaries; *S*₁ to light the filament of a type H-1 kenotron *K* and *S*₂ to provide 1,550 volts rms which is rectified to give 2,200 volts d. c. In order to smooth out the rectified voltage, the capacitance, *C*, consisting of two 2 μ f condensers in series, is inserted between ground and the high side. A protective resistance, *R*, of several megohms prevents an accidental dangerous flow of current. The voltage is led to the chamber by means of a rubber-covered cable, *D* (fig. 3), surrounded by a grounded copper "pigtail" sheath.

³⁰ L. S. Taylor, B. S. Jour. Research, **3**, p. 807; 1929.

³¹ L. S. Taylor. See footnote 27, p. 507.

³² A current-balancing null system was first employed, using for this purpose a uranium oxide ionization chamber in which the ionization current was adjusted by a large iris diaphragm placed about 1 mm from the uranium oxide covered plate. Since then Failla³³ and Jaeger³⁴ have devised better forms of ionization compensators; hence, it is planned in the future to use a radium-compensating chamber devised and very kindly furnished us by Dr. Failla. This system provides a wide range of currents and lends itself well to transportation with unaltered calibration.

³³ G. Failla (seen in MS. form. Read at Toronto, Dec. 3, 1929).

³⁴ R. Jaeger, Strahlen., **33**, p. 542; 1929.

III. ADJUSTMENT AND ALIGNMENT

From the foregoing it is evident that the chamber closely resembles the standard chamber already described.³⁵ This is highly desirable, since it makes the conditions of alignment and diaphragming identical for the two and consequently minimizes uncertainty due to corrections which must otherwise be made.

As with the primary standard, the alignment with respect to the X-ray tube is fairly critical. For experimental test the chamber was mounted on a 2 m track, *T* (fig. 3), placed parallel to the X-ray beam and pivoted so as to rotate horizontally about its center. Lateral adjustment in the X-ray beam is effected by moving the X-ray tube. (For field use the chamber is mounted on a short track providing the lateral motion.)

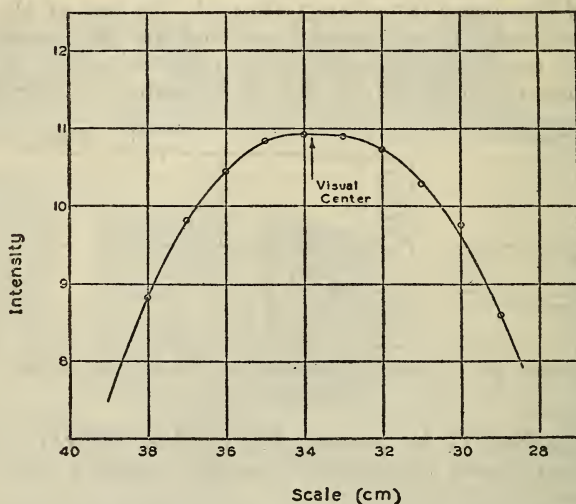


FIGURE 6.—Cross section of beam to obtain lateral alignment of ionization chamber

Preliminary visual alignment of the ionization chamber is made by sighting through the diaphragm system at the focal spot. This is facilitated by a cross line marked on the celluloid window at the back of the chamber. With the small focus X-ray tube, such adjustment is fairly accurate as shown in Figure 6, but it has been found unsafe to rely upon this method alone, particularly when used with a broad-focus tube. In all cases ionization readings are made successively as the X-ray tube is shifted laterally in a direction at right angles to the beam, and thus a measure of the intensity distribution across the beam is obtained. The final position of the chamber is that corresponding to the center of the intensity distribution peak. Likewise the chamber is tested for its angular alignment by measuring the ionization as it is rotated through a small angle about its center. Visual centering is more reliable in this case. Figure 7, showing the ionization intensity as the chamber is rotated, indicates the small range of adjustment possible; even

³⁵ L. S. Taylor. See footnotes 14 and 15, p. 508.

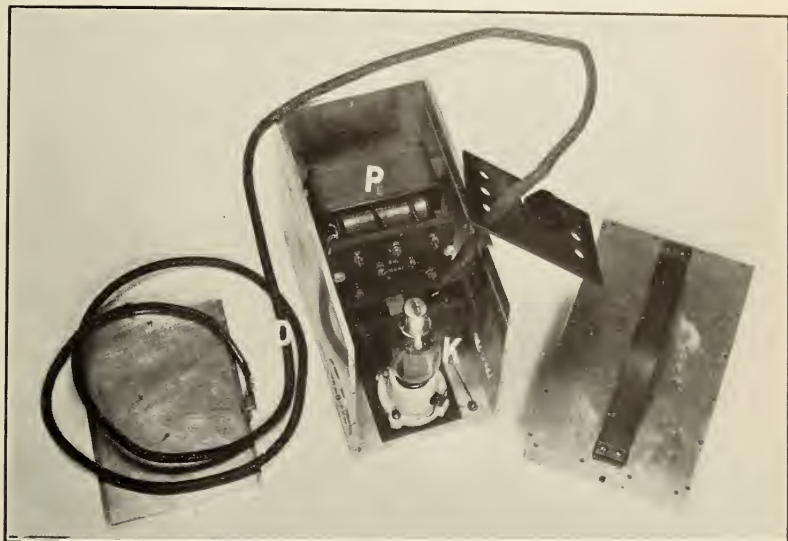


FIGURE 5.—2,200-volt D. C. kenotron rectifier unit (cut away to show construction)



with a fairly broad beam a rotation of over 1° in either direction will cause an error in the measurements.

For studying the behavior of this chamber, two X-ray tubes of the 200 kv Coolidge deep therapy type were employed. The first had a fine, very closely defined focal spot, while the second had a broad, poorly defined focal spot with a "black center," these selections representing the two extremes ordinarily encountered in practice. Measurements with the standard chamber revealed a strict adherence to the inverse square law of intensity for the first tube and to the inverse 2.1 power for the second.

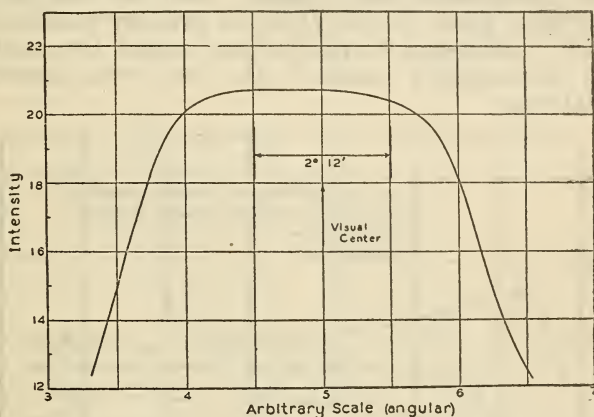


FIGURE 7.—Cross section of beam to obtain angular alignment of ionization chamber

IV. PERFORMANCE

To be certain that the potential wires provided proper field correction, saturation conditions were studied as for the primary standard chamber; four different measuring methods were used for which the saturation curves are shown in Figure 8. Curve *A* is for a system in which the collector plate is allowed to discharge to a potential below that of the guard electrodes; Curve *B* for a collector charging above the guard potential; Curve *D* for an idiostatic measurement, and *C* for a null compensation measurement. It is seen from these curves that the behavior is almost identical with that of the primary standard chamber using wide guard electrodes.³⁶

The extent to which radiation was scattered from the diaphragms and potential wires was next investigated. A photographic film placed against the wires at the back of the chamber showed no shadow whatever of the wires after a long exposure with the aligned beam passing through the chamber. This indicates that scattering from the wires is negligible.

The second diaphragm used to reduce the effect of scattering from the limiting diaphragm is necessary as shown by the inverse square law curves. (Fig. 9.) Curve *A* shows for the standard chamber, the logarithm of the intensity as a function of the logarithm of the distance measured between the focal spot of the broad focus tube

³⁶ L. S. Taylor, see footnote 14, p. 508.

and the front of the chamber diaphragm, which was set at the same diameter (0.8 cm) as that of the secondary chamber under investigation. From the slope of this plot it is found that the intensity obeys the inverse 2.1 law. Repeating the same observations with the secondary standard, curve *B* was obtained, showing a close parallel to the standard chamber within the experimental error. The scattering diaphragm, *S* (fig. 1), was then removed from the back of the lead tube and, again repeating the run, curve *C* was obtained, showing a marked divergence from the results obtained with the standard chamber. The need of the back diaphragm, *S*, is thus clearly evident.

The observations were next repeated, using the fine focus instead of the broad focus tube. Curve *D* for the primary standard chamber shows a strict adherence to the inverse square law, and likewise curve *E* for the secondary standard—the two curves agreeing within experimental error.

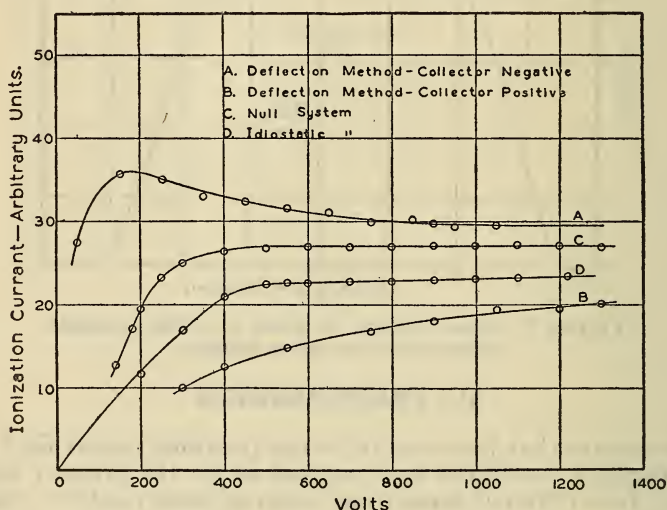


FIGURE 8.—Saturation curves for new ionization chamber as obtained by four methods

These are almost identical with saturation curves for the large standard chamber.

The final measure of accuracy obtainable with the chamber is by a direct comparison with the primary standard chamber. To rule out any differences in the two electrometer systems for preliminary measurements, the same electrometer and compensating system was used for both chambers without necessitating any changes whatever in either the system or its connections. Both chambers were charged by the same source of high potential; in making observations, it was only necessary to shift the tube from one chamber to the other—a matter of about half a minute.

The effect of altering the size of the limiting diaphragm next to the X-ray tube was investigated, maintaining both chambers at the fixed distance of 75 cm from the target. These data show that the two chambers fluctuate in the same manner, due to the uneven distribution of energy over the focal spot and off-focus radiation.³⁷

³⁷ L. S. Taylor, B. S. Jour. Research, 3, p. 807; 1929.

Table 1 summarizes the data obtained. Column 2 gives the $r/\text{min.}$ measured with the primary standard chamber and column 3 the percentage mean deviation of the observations made for each point. Likewise columns 4 and 5 give, respectively, the $r/\text{min.}$ and the mean deviation of observations made with the secondary chamber. Column 6 shows the percentage agreement in the $r/\text{min.}$ as measured with the two chambers, indicating that, in general, the agreement is within the observational error. All of the measurements thus far have been made with the same null electrostatic measuring system.

The final check was made using two entirely separate electrostatic current measuring systems. A few of the measurements taken under random conditions are shown in Table 2, which needs no explanation.

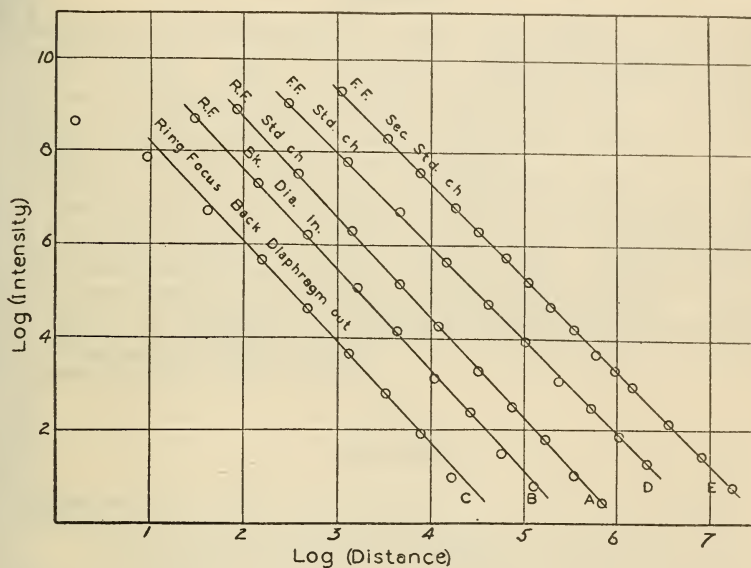


FIGURE 9.—Inverse square law curves for primary and secondary standard chambers

Logarithms shown are only to give slope and do not apply directly to the experimental points shown.

TABLE 1

Diameter of tube diaphragm	$r/\text{min.}$ primary standard	Deviation	$r/\text{min.}$ small standard	Deviation	Difference
1	2	3	4	5	6
20-----	33.1	Per cent ± 0.2	32.6	Per cent ± 0.4	Per cent -0.7
18-----	32.8	.2	32.8	.1	.0
16-----	32.8	.3	33.0	.1	+ .3
14-----	32.6	.2	32.6	.5	.0
12-----	31.6	.2	31.6	.3	.0
10-----	30.0	.2	30.4	.3	+ .6
8-----	24.2	.2	24.3	.2	+ .2
6-----	18.8	.2	18.6	.0	-.5
4-----	9.9	.2	9.9	.1	.0
Average difference-----					$\pm .26$

TABLE 2

Primary standard			Secondary standard			
Tube distance	Chamber diaphragm	$r/\text{min.}$	Tube distance	Chamber diaphragm	$r/\text{min.}$	Agreement
<i>cm</i>	<i>cm</i>		<i>cm</i>	<i>cm</i>		<i>Per cent</i>
94.5	0.8	14.00	94.5	0.8	14.25	± 0.8
94.5	.8	5.24	94.5	.8	5.26	$\pm .2$
87.2	.8	6.23	87.2	.8	6.18	$\pm .4$

WASHINGTON, March 1, 1930.



